TURBULENT FLAME SPREAD ON CORNER WALLS

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Introduction

The work reported here is part of a continuing program to establish a reliable database for predicting fire spread on vertical corner walls. In a corner fire, transient three dimensional fire-induced flow causes a complex convection and radiative heat transfer to the corner walls [1]. In our previous work, the fire-induced flow was investigated first [2], and then an automated infrared imaging system was developed to measure transient wall temperature distributions [3]. Using the IR imaging system the progress of pyrolysis front on corner walls was measured successfully [4]. The motivation for the present study is to characterize the flame spread and heat transfer from flame to the wall surface.

Experimental Design

A schematic of the corner wall flame spread facility is shown in figure 1. The room corner model is 1.6m high x 1.0m wide x 1.0m long with ceiling and floor, made of Marinite boards. Polymethymetharylate(PMMA, 2cm thick)) samples were flush mounted and fixed on to the corner walls. In these experiments, ignition was provided at the bottom of both side walls by a small propane torch. To prevent excess preheat of the virgin surface, the sample was covered by a Marinite board except the ignition zone. When the cover was removed after the whole ignition zone was ignited, a sustained flame spread was achieved. When the peak of pyrolysis front reached the top of the sample, the flame was extinguished by a sudden purge of CO_2. During the flame spread, two dimensional spreading pyrolysis front was detected by tracing isothermal line with T_{ig} using an automated infrared imaging temperature measurement system(AIIT). The principal assumption made here is that the pyrolysis front reaches a point exactly when the surface temperature at that point just reaches the ignition temperature T_{ig}. The accuracy of the measurement associated with determination of T_{ig} and elimination of flame interference has been discussed in references [3] and [4]. A typical result obtained by the AIIT is given in figure 2. The visible flame shape was simultaneously recorded by a video camera, from which a time averaged visible flame height was deduced. Based on the pyrolysis front measurement, total heat flux histories at those points along the trajectory of the peak of the pyrolysis front were measured by Gardon-type heat flux sensors with automatic data recording and storage on a computer disc.

Results and Discussion

(1) Effect of Ignition

Typically, a fire ignited on a section of corner wall spreads vertically and horizontally. Different ignition methods correspond to various spread modes. In our previous work the effect of unsymmetric ignition(one side ignition) has been discussed [4]. This study reports the fire spread phenomena in a symmetric line ignition mode along the bottom of corner walls. When the PMMA corner model is ignited on both sides symmetrically, and the height of ignition zone is fixed(3cm), then the length of ignition zone L is the only controlling parameter for this simulated fire scenario. The effect of ignition length on flame spread was investigated first. Three flame spread experiments were conducted with the ignition length 10, 30 and 40cm respectively. The height of the samples is 1.0m. During the flame spread process, a M-shaped pyrolysis front always appeared. The maximum upward spread rate was achieved at the peak of the M-shaped pyrolysis front. Figure 3 shows vertical and horizontal pyrolysis fronts X_p and Y_p as functions of time with different ignition lengths.We found the vertical spread rate increase with increasing ignition length to some critical value, and then decrease slightly or remain constant. To determine the critical ignition length, the

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time elapsed when the pyrolysis front reaches the sample top is plotted as a function of the ignition length in Figure 4(some results from our previous tests). We found when $L \geq 20$cm the vertical flame spread rate achieves its maximum value and then keeps constant approximately. In figure 3 the horizontal flame spread is minor and approximately constant regardless of ignition length.

(2) Heat Transfer from the Flame

A first step has been taken to characterize heat transfer process in preheat region so that upward flame spread might be predicted. Heat flux test was performed with a 100x35cm PMMA corner model, ignition length is 30cm on each side. Total heat flux histories were measured at three different positions distributed along the trajectory of pyrolysis peak, that was located in previous experiment. Figure 5 shows the measured incident total heat flux versus time at the three positions, t_f and t_p correspond to the moments when the flame tip and pyrolysis front reach the measuring point respectively. There is no significant increase in heat flux when the flames begin to cover the measuring point, so a visible flame height is probably not ideal to consider as preheat characteristic length for the corner fire(this assumption is usually made for flame spread on a vertical flat surface[5, 6]). We also found heat flux change with time in pyrolysis region, the maximum heat flux 3.5 w/cm^2 was achieved at point B in the pyrolysis zone. The value at point C is supposed going up if not extinguished.

(3) Flame Spread Characteristics

In the M-shaped pyrolysis front spread mode, vertical spread at the peak and horizontal spread at the base are critical aspects of the flame spread phenomena. Associated to our previous study on fire induced flow along the corner wall [2], it can be identified that the vertical flame spread is a concurrent flow spread(in the direction of local gas flow) and horizontal flame spread is an opposed flow spread(opposite to the local gas flow). Their spread characteristics are discussed separately as follow.

(a) Horizontal Spread

From Quintiere and Harkleroad(1984) [7, 8], downward and lateral spread in air on a vertical surface can be expressed as follows:

$$V_p = \frac{\phi}{(k\rho c)(T_{ig} - T_s)^2} \quad (1)$$

where ignition temperature $T_{ig} = 378$ °C, effective thermal inertia $k\rho c = 1.02$ (kw/m^{2}K)^{2}s and flame heat transfer parameter $\phi = 14.4$ (kw)^2/m^3 for PMMA. From our corner fire experimental results(figure 3), $V_p = 1.13 \times 10^{-4}$m/s. By equation (1) we can calculate $\phi = 13.98$(kw)^2/m^3, that is very close to the value in single vertical surface case. It was believed that the enhanced radiant heat transfer by the other side wall fires was offset by a stronger opposed flow confined by corner walls. We also found a similar mechanism that causes the approximate constant lateral spread rate.

(b) Vertical Flame Spread

In our previous study , corner fire vertical spread rate is about two times faster than that of similar scale flat vertical surface fire($V_p = 0.0074\, X_p^{1.05}$ versus $V_p = 0.00441 X_p^{0.964}$)[4, 5]. The high spread rate is mainly contributed to a strong fire induced flow that enhanced heat convection from the flame to the wall surface. There exists a critical ignition length beyond it flame spread rate does not increase any more, probably because the fire induced flow in the corner can not be enhanced any more. To understand heat transfer process, we assume the lateral heat diffusion inside the sample can be neglected, or a one dimensional heat conduction model is applicable in the preheat region, it can be shown [9] the surface temperature of a semi-infinite slab initially at the uniform temperature T_o, subjected to a uniform net heating flux $\psi(t)$ is given by

$$T_s(t) = T_o + \frac{1}{\sqrt{\pi k\rho c}} \int_0^t \frac{\psi(\tau)}{\sqrt{t-\tau}} d\tau \quad (2)$$

By equation (2), proposed by Mitler(1990) [10], a pyrolysis temperature T_p can be computed based on the measured incident heat flux history in the preheat period(from $t = 0$ to $t = t_p$), and compared with already known pyrolysis temperature. For this purpose heat flux history ($0 < t < t_p$) was fit by a three order polynomial, and then introduced into equation(2). The calculated pyrolysis temperatures for the three positions are much lower than the well known value (378 °C from reference[7], 370 °C from reference [4]). This results suggest that lateral heat diffusion is important to predict the vertical flame spread along corner walls.

Conclusion

The flame spread on vertical corner walls and the heat transfer mechanism have been addressed experimentally and theoretically. One dimensional heat transfer model using flame height as the heat transfer characteristic length may be not applicable to corner fire spread. Obviously, a measurement of lateral heat conduction inside the sample slab is a necessary addition to the measurement of heat transfer from the flame to develop prediction models. Other two key results emerge from this study are: (1) Vertical flame spread rate achieves its maximum value with ignition length $L \geq 20$ cm; (2) Horizontal flame spread rate is constant and the same level as that on single vertical surface.

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Reference

[1] Daikoku, M., Lin, W.X. and Saito, K., " Visualization of Fire-induced Flow", *Proc. the Central State Section, The Combustion Institute,* Nashville, TN. April,1991.

[2] Qian, C. and Saito, K., *Proc. Asian Conference on Fire Science and Technology* Hefei, China, 1992, pp.257-262

[3] Arakawa, A., Saito, K. and Gruver, W.A., Combustion and Flame, 92:222(1993)

[4] Qian, C., Isihda, H. and Saito, K., *Proc. Central and Eastern States Section, The Combustion Institute,* New Orleans, LA. March, 1993. pp.616-620

[5] Orloff, L., deRis, J. and Markstein, G.H., *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, 1975, pp. 183-192

[6] Saito, K., Quintiere, J.G. and William, F.A., *Fire Safety Science-Proceedings of The First International Symposium,* Hemisphere Pub., 1985, pp.75-86

[7] Quintiere, J.G. and Harkleroad, M., New concept for measuring flame spread properties. Symp. on Application of Fire Science to Fire Engineering, Amer. Soc. Testing and Materials/Soc. Fire Prot. Engrs., Denver. (1984)

[8] Quintiere, J.G., Harkleroad, M. and Masemi, Y., *Combust. SCI. and Tech., 1986,* Vol. 48, 191-222

[9] Carslaw, H. S. and Jaeger, J. C., Conduction of Heat in Solids, 2nd ed., Oxford, 1959.

[10] Mitler, H. E., *Twenty-Third Symposium (International) on Combustion The Combustion Institute,* 1990/pp. 1715-1721

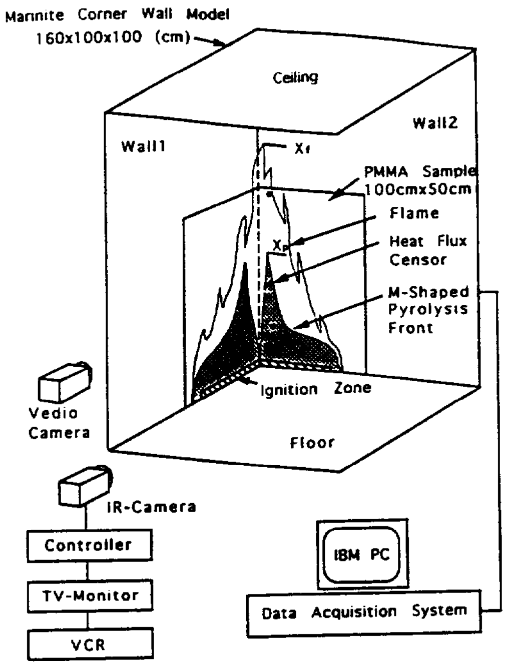

FIG. 1 Schematic of apparatus, flame shape and pyrolysis region

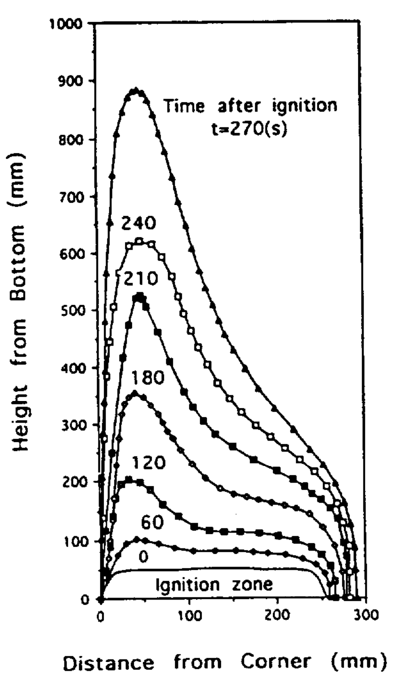

Fig. 2 Progress of the 329°C isotherm that corresponds to the pyrolysis temperature of PMMA determined by IR image system

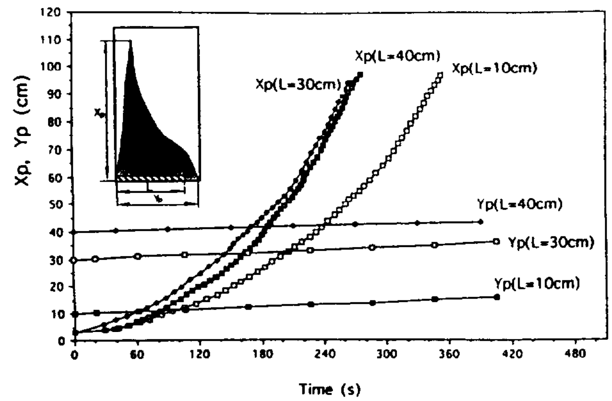

Fig.3 Height and width of pyrolysis region as functions of time with different ignition lengths

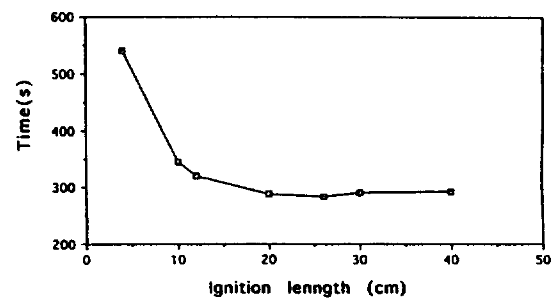

Fig.4 Time elapsed after ignition when the pyrolysis front reaches the samlpe top with different ignition lengths

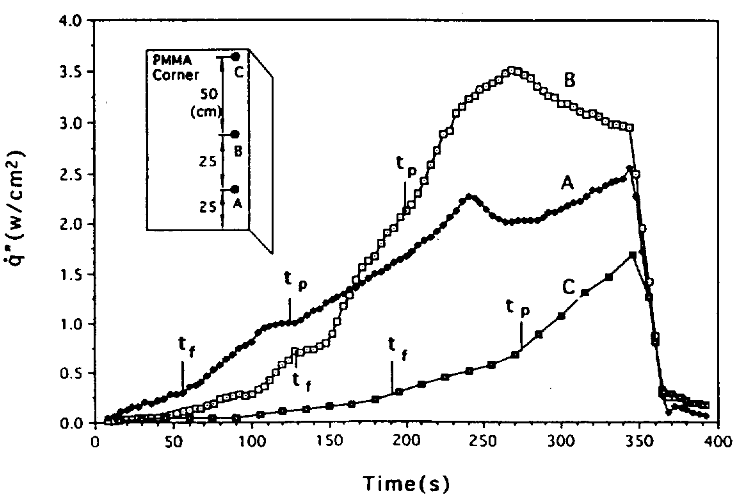

Fig. 5 Heat flux histories at A, B and C positions